

Inertial-Electrostatic Confinement Fusion in Japan.

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Dr. Kiyoshi Yoshikawa, Institute of Advanced Energy, Kyoto University, Japan, describes Potential Well Measurements by the Laser-Induced Fluorescence Method in an Inertial-Electrostatic Confinement Fusion Device. Inertial-Electrostatic Confinement Fusion (IECF) was first proposed in the 1950's aiming at future fusion power plants. It is basically a beam-beam colliding fusion device with an extremely compact and simple configuration. Working with Farnsworth at ITT laboratories in the U.S., Hirsch obtained in 1967 record neutron outputs of approximately 10×10^8 n/s and 10×10^{10} n/s for D-D and D-T, respectively, from a gridded TECF device driven by six ion guns.

After a long pause in the research, a new concept came out at the University of Illinois (URIC) early in the 1990's, primarily involving use of a single wire-cathode grid and discovery of a new discharge mode without complicated ion guns. This resulted in a potentially promising compact neutron source for versatile industrial applications. Since then, IECF research based on this concept has been carried out widely at various institutions in the world, leading to the currently highest steady-state neutron yields of 5×10^7 neutrons/s for D-D and 7×10^6 protons/s for D-3He at the University of Wisconsin, as well as the much higher neutron production of 7×10^8 n/s during the peak of each pulse operated in the large-current pulse mode (17 Amps, 100 s, 10 Hz) at URIC.

For further dramatic improvement of the fusion reaction rate, however, it is essential to clarify the mechanism of potential well formation, which is predicted to develop in the central plasma core of the cathode. Potential well formation due to space charge associated with spherically converging ion beams plays a key and essential role in the beam-beam colliding fusion, i.e., the major mechanism of the IECF devices. This has been the central issue for IECF researchers for the past 30 years. The first successful direct measurement of the double-well potential profile was made in an IECF device through the Laser-Induced Fluorescence (LIE) method at Kyoto University in 1999 with an approximately 200 V dip at the center in a helium plasma core, as described below.

Many theoretical results have predicted strongly localized potential well formation, and many experiments were dedicated to clarifying this mechanism using, for example, electron beam reflection, spatially collimated neutrons or proton profile measurements, or an emissive probe, but none seems to be conclusive in convincing researchers that a well does form. Recently, theoretical results predicted a very promising new nonlinear regime for dramatically enhanced fusion reaction rates in a relatively large current (perveance) region. These results urgently call for diagnostics with a higher degree of temporal and spatial resolution for verification than has been achieved by the conventional methods.

In order to cope with this urgent issue, scientists in Japan have adopted optical diagnostics using the Stark effect, which is sensitive to local electric fields, to the IECF device with a hollow cathode. Also, to enhance the signal to noise (S/N) ratio as well as to analyze the radial potential profile, they introduced the LIE method. Consequently, they have measured a double-well potential profile with an approximately 200 V dip at the center for the first time in the helium plasma core of the Kyoto University IECF device.

The LIF system consists of a Nd:YAG laser, a dye laser to produce 504.2 nm light to cause the forbidden transition through Stark and quadrupole (QDP) transitions from 21S atoms to 31D states of HeI. The LIE (667.8 nm) is then observed to provide peak spatial profiles that result in the profiles of degree of polarization, from which spatial electric field, thus potential, can be obtained. The operating conditions were chosen as: He pressure of 20-30 mTorr, cathode voltage of 7-11 kV, cathode current of 30-40 mA (regulated) to enhance the beam perveance.